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Heat Recovery from Flue Gases in Office and Apartment Buildings

A RESEARCH REPORT

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Heat Recovery from Flue Gases in Office and Apartment Buildings

A RESEARCH REPORT

A Review of Flue-Gas Heat Recovery Technology for Heating Plants in Offices and Medium to High Rise Apartment Buildings

Sponsored by the
Energy Conservation and Oil Substitution Branch
Energy, Mines and Resources Canada

Prepared by
Energy Systems Centre
Engineering Sciences Division
Ontario Research Foundation

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ABSTRACT/RESUME

This report presents an overview of the existing technology for flue-gas heat recovery from typical heating plants in apartment and office buildings.

Emphasis is placed on commercially available equipment that could be used for reclamation of waste heat for boiler feed water heating or combustion air preheat. Both condensing and non-condensing heat exchange technologies are examined.

The study examines and documents a variety of heat recovery equipment in terms of performance, capacities, operation and maintenance requirements. It establishes system selection criteria and provides a basis for evaluating the economic viability of energy recovery investments.

Finally, the study reviews related codes and standards to identify potential constraints that may exist.

* * *

Le rapport qui suit donne un aperçu des techniques courantes de récupération de la chaleur résiduelle des gaz de combustion de l'installation de chauffage qu'on trouve habituellement dans un immeuble d'appartements ou de bureaux.

Il concerne surtout le matériel du commerce qui pourrait servir à récupérer la chaleur résiduelle pour préchauffer l'eau amenée à la chaudière ou l'air comburant. On examine les techniques d'échange de chaleur avec et sans condensation.

Le rapport fait état de divers appareils de récupération de chaleur et donne des renseignements sur leur rendement, leur puissance, leur fonctionnement et leur entretien. Il propose des critères de sélection pour les systèmes et établit les principes d'évaluation de la viabilité des placements en récupération de chaleur.

Enfin, un relevé des normes et codes pertinents permet de cerner les restrictions qui pourraient exister. Le lecteur trouvera un sommaire, en français, de ce rapport à la page ii.

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This report has been prepared to assist owners and operators of office buildings and apartment buildings in developing effective strategies in energy conservation. Specifically, the report highlights the state-of-the-art of flue gas heat recovery techniques which could be used in office and apartment buildings. Information contained in the report is considered current as of March 1982 when the report was prepared. Little has happened subsequent to this time, however, which would significantly affect the findings of the report, with the exception of generally lowered interest rates.

The primary effect of lowered interest rates is to reduce costs for heat recovery equipment, thereby increasing the likelihood of short payback periods.

This report was prepared by the Ontario Research Foundation. The sponsoring agency was Energy, Mines and Resources Canada, through the Building Energy Technology Transfer (BETT) Program.

The aim of the BETT Program is to promote widespread adoption of energy conservation in buildings by providing the necessary technological know-how and effecting its delivery to the appropriate end-users.

Le présent rapport fait le point sur le matériel qui peut être employé dans les immeubles d'appartements et de bureaux, pour récupérer la chaleur résiduelle des gaz de combustion.

Les travaux effectués visaient à déterminer si le matériel existant convient aux genres d'immeubles susmentionnés, à estimer les économies d'énergie possibles et les frais engagés et à voir si le matériel était d'usage courant dans ces immeubles. L'étude s'est faite de façon empirique surtout : on a communiqué avec des fabricants pour obtenir les caractéristiques de rendement et les données économiques relatives aux installations connues de récupération de la chaleur résiduelle des gaz de combustion.

On a contaté à l'examen des renseignements recueillis que les économies possibles sont de l'ordre de 10 p. 100 à 15 p. 100, en ce qui concerne les installations de chauffage courantes des immeubles de bureaux et d'appartements. Malgré cela, la technique semble très peu employée. Il ressort toutefois des critères économiques établis dans le présent rapport que la récupération de la chaleur résiduelle des gaz de combustion peut être une solution fort intéressante. Le rapport traite en outre des techniques fondamentales employées pour faire une évaluation plus détaillée de tout investissement dans ce domaine.

Il semble qu'aucun règlement n'empêche l'emploi de matériel de récupération de la chaleur résiduelle des gaz de combustion dans les immeubles de bureaux et d'appartements. Il peut toutefois y avoir certaines restrictions en ce qui concerne l'acidité du condensat que peut produire ce matériel. Il semble enfin que les systèmes sans condensation soient plus rentables, en général, que les systèmes à condensation.

As a part of the Buildings Energy Technology Transfer Program, it was decided to investigate the potential for energy conservation through retrofitting flue gas heat recovery equipment to heating plants in office and apartment buildings.

To this end a task was undertaken early in 1982 to attempt to identify any potential energy savings which might be expected from flue gas heat recovery equipment in the above mentioned applications.

The findings of the study are presented in this report.

1.1 Objectives

The objectives of the study can be summarized as follows:

1. To provide a state-of-the-art review of technology for flue-gas heat recovery in apartment and office buildings
2. To identify energy conservation potential realizable through application of this technology
3. To provide a basis for a rational evaluation of "costs" versus "benefits" of energy savings
4. To identify potential barriers to installation of heat recovery equipment.

1.2 Method and Scope of Study

1. In order to determine the current state of the art, a number of consulting firms and related equipment manufacturers (Appendix I) were contacted. In addition, literature search and actual field visits were also undertaken. Emphasis was placed on collection of the technical and economic data on commercially available equipment suitable for typical apartment and office buildings.

2. Assessment of the technical feasibility of commercially available flue gas heat recovery equipment was undertaken. This included a review of literature on corrosion of heat exchangers and development of design parameters for the most suitable concept for this application.

3. Economic evaluation of the most suitable concept using established investment analysis techniques was carried out.

4. Various barriers to implementation, e.g. costs, lack of awareness etc., were investigated. The impact of these barriers on the adaptation of this type of energy recovery system to existing and new buildings was assessed.

2.1 Options in Flue-Gas Heat Recovery

This section provides an overview of alternatives available for flue-gas heat recovery in apartment and office buildings. Emphasis is placed on heat recovery devices which are commercially available. The various types of heat recovery units are summarized in Table 2.1 and discussed further below.

TABLE 2.1. SUMMARY OF COMMERCIALLY AVAILABLE HEAT RECOVERY UNITS

Gas-to-Water Heat Reclamation	Gas-to-Air Heat Reclamation
1. Finned-tube (economizer)	1. Heat-pipe
2. Direct-contact: a) Spray heat b) Baffle tray c) Packed bed	2. Rotary 3. Plate-type

2.1.1. Gas-To-Water Heat Reclamation

Two types of equipment are commercially available:

*Finned-tube heat exchangers

*Direct-contact heat exchangers.

Finned-tube heat exchangers may be used to reclaim heat from flue gas for domestic water heating or pre-heating feed water for boilers. This application is commonly known as an "economizer". Waste heat is reclaimed by water circulating inside finned tubes. The fins are employed to enhance heat transfer on the flue gas side.

Several types of finned-tubes are commercially available. For a given situation, the best performance is achieved with the flue-gas streams perpendicular to cylindrical fins. Intermediate performance is achieved for flow parallel to discontinuous strip fins and lowest performance is for flow parallel to continuous fins. Serrated fins are superior to solid fins since fin serrations cause turbulence in the gas stream and this increases the heat transfer coefficient.

A typical commercially packaged unit is illustrated in Figure 2.1. Other arrangements are shown in Figures 2.2. and 2.3. where the heat reclaimer is placed above the boiler, connecting the boiler flue gas outlet and the chimney. A temperature sensor, located downstream of the heat reclaimer, controls the operation of the economizer water pump. In general, the temperature is set to maintain flue-gas temperatures of 120 C (250 F) for gas-fired boilers and 150 C (300 F) for boilers using No. 2 fuel oil. These temperatures are chosen to minimize the occurence of acidic condensation.

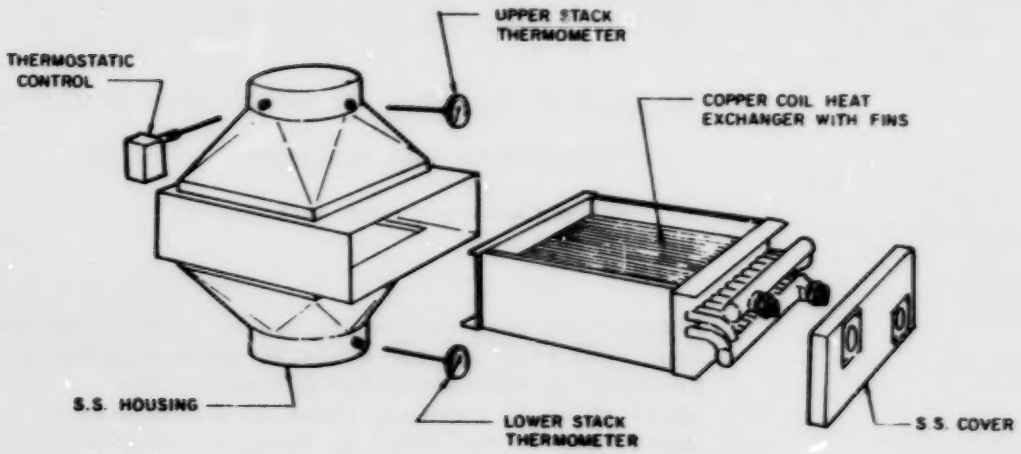


FIGURE 2.1. FINNED-TUBE HEAT RECLAIMER

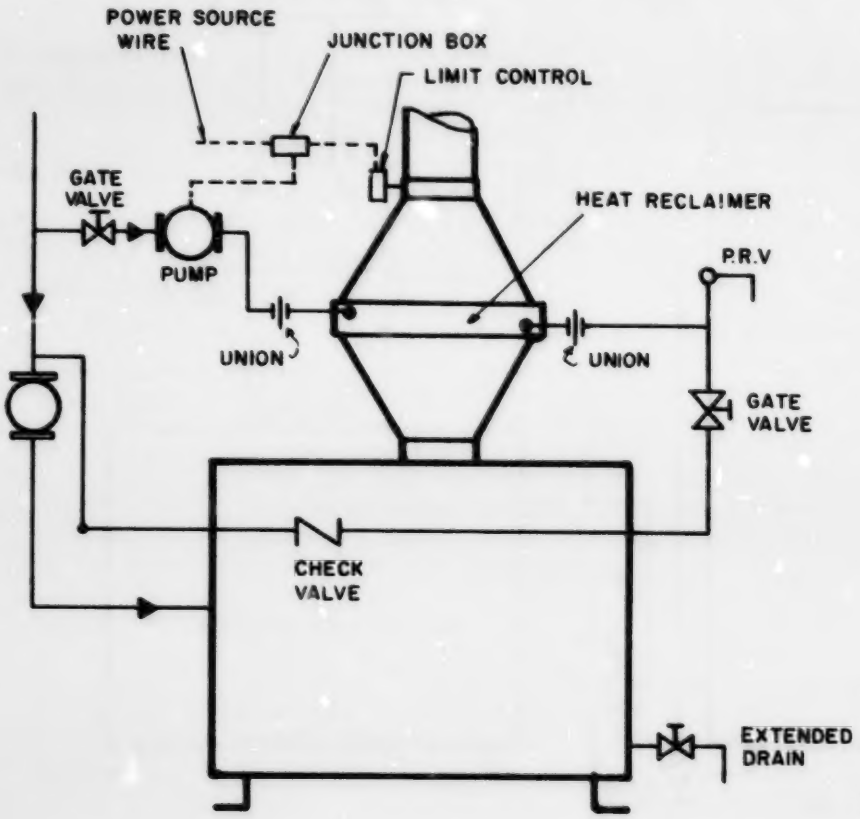


FIGURE 2.2. HEAT RECLAIMER INSTALLED ON A TYPICAL HOT WATER SYSTEM

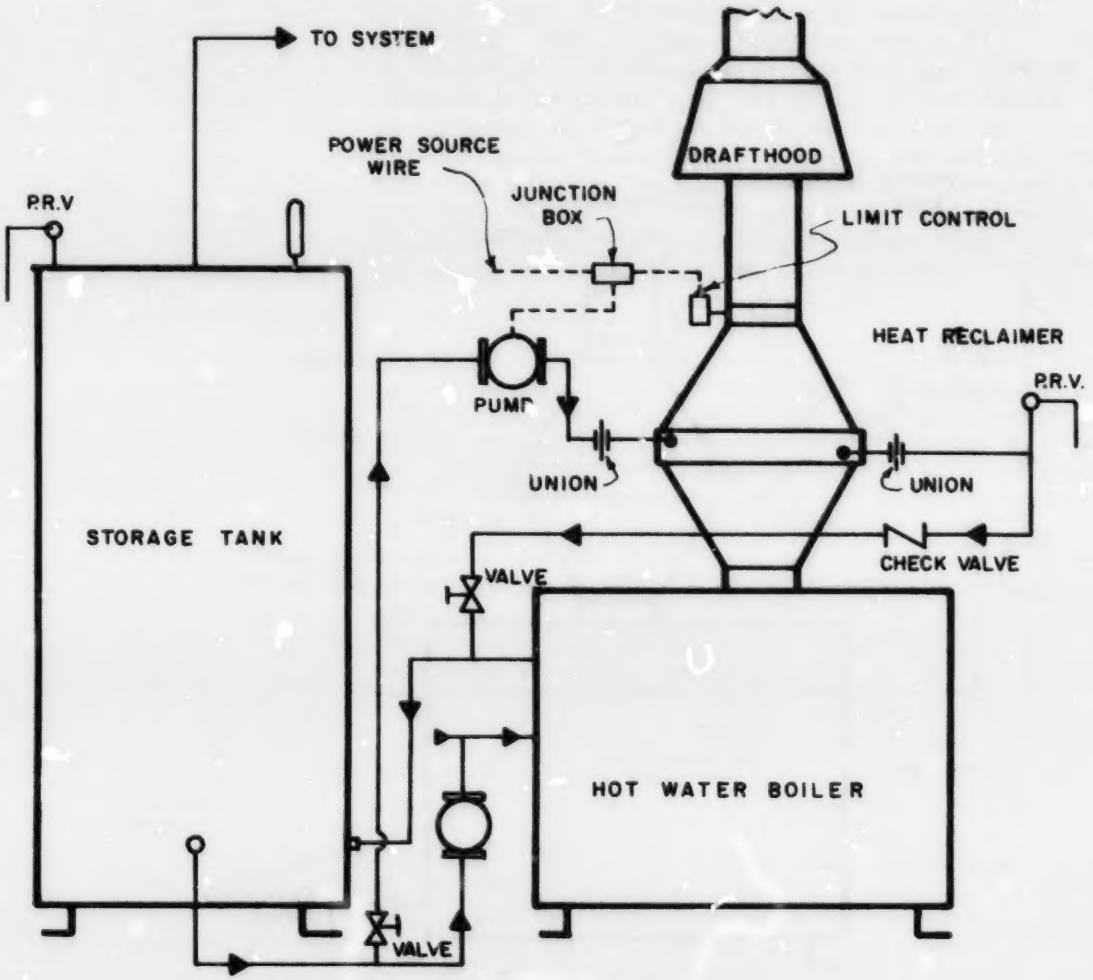


FIGURE 2.3. HEAT RECLAIMER INSTALLED ON BOILER WITH STORAGE TANK

Various materials for fins and tubes are used commercially, including copper, aluminum, low-alloy and high-alloy steels. For gas-fired systems, finned copper tubes are generally recommended. For oil-fired units, finned-tubes made from high-alloy steel are recommended for compatibility.

The flue-gas pressure drop across the heat reclaimer must be limited in order to avoid interference with the combustion process. For fuel-burning systems equipped with atmospheric burners this pressure drop should be held to less than 0.05 inch water column. However, for power burners larger pressure drops can be tolerated.

Commercial units are available for gas-fired or No. 2 oil fired systems with capacities ranging from 29 kW (100 000 BTU per hour) to 4 400 kW (15 000 000 BTU per hour). Heat exchanger effectiveness depends on the baseline efficiency of the system. Typically 5 to 15% fuel savings may be realized. Interviews with heat exchanger manufacturers suggested that equipment costs range from $1 000 for small units, to $20 000 for large units.

Direct-contact heat exchangers operate on the wet scrubbing principle, where water is sprayed into the flue gas to reduce the temperature below its dew point, thereby recovering latent as well as sensible heat.

Direct-contact heat exchangers for flue-gas heat recovery are quite popular in Europe, but only recently have they been marketed in North America.

Direct-contact heat exchangers can be generally classified in three categories:

1. Spray heat exchangers: A spray heat exchanger essentially consists of a cylindrical vessel. The hot flue gases enter the vessel at the bottom and are cooled by a spray of water fed from nozzles located at the top. The two streams are in direct contact inside the exchanger.

2. Baffle-tray heat exchangers: A baffle-tray heat exchanger is a spray heat exchanger which contains baffles to promote heat transfer performance by increasing contact surface and residence time for the two streams.

3. Packed-bed heat exchangers: A packed-bed heat exchanger is a direct-contact exchanger packed with granular solids to promote high contact surface area.

Direct-contact heat exchangers are generally made of high-alloy steel; consequently they are relatively expensive. Heat exchanger manufacturers recommend this type of equipment for gas-fired boilers only. For oil-fired units the high sulphur content in fuel degrades the quality of the working fluid to an unacceptable level unless frequently diluted with fresh fluid or other treatment methods are used.

Direct-contact heat exchangers are high-efficiency units which recover both sensible heat and latent heat from flue-gas. According to figures provided by a European Company, (Material Thermique et Chaudronnerie Union), the capital costs for these units are triple those for finned tube economizers.

Figure 2.4. shows a commercially available direct-contact flue-gas heat recovery system.

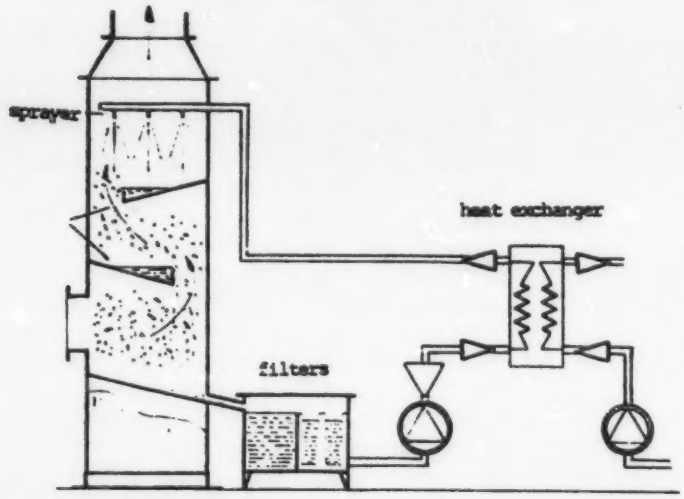


FIGURE 2.4. DIRECT-CONTACT HEAT RECLAIMER USED FOR INDIRECT WATER HEATING

2.1.2 Gas-to-Air Heat Reclamation

The following types of heat exchangers are commercially available:

1. Heat-pipe heat exchangers
2. Rotary heat exchangers
3. Plate type heat exchangers.

Heat pipe heat exchangers. A heat pipe consists of three components:

- a sealed container
- a capillary wick structure
- a working fluid.

In operation, heating one end of the heat pipe causes evaporation of the working fluid. The conversion of the fluid to vapour creates a pressure gradient within the heat pipe. The vapour then travels to the opposite end (condenser end) of the pipe, which is at a lower temperature. The vapour condenses and releases latent heat. Heat is removed from the condenser end. A continuous process is established by the capillary pumping force within the wick structure or gravity, which returns the fluid to the evaporator section. Fins can be used to promote heat transfer.

Aluminum, copper and low alloy steels are commonly used materials for tubes and fins. As explained earlier, flue-gas temperature and sulphur content influence material selection.

An example of a heat-pipe heat exchanger is shown in Figure 2.5.

Unit performance of heat pipe heat exchangers varies with gas flow, a velocity range of 2 m/s to 4 m/s (6 to 12 ft/s) being accepted to keep the pressure drop across the heat pipe bundle to a reasonable level. Packaged heat-pipe recovery units are commercially available from a number of sources in Canada. Capacities of these units range from 350 L/s (750 scfm) to 6 000 L/s (12 500 scfm) flue gas flow.

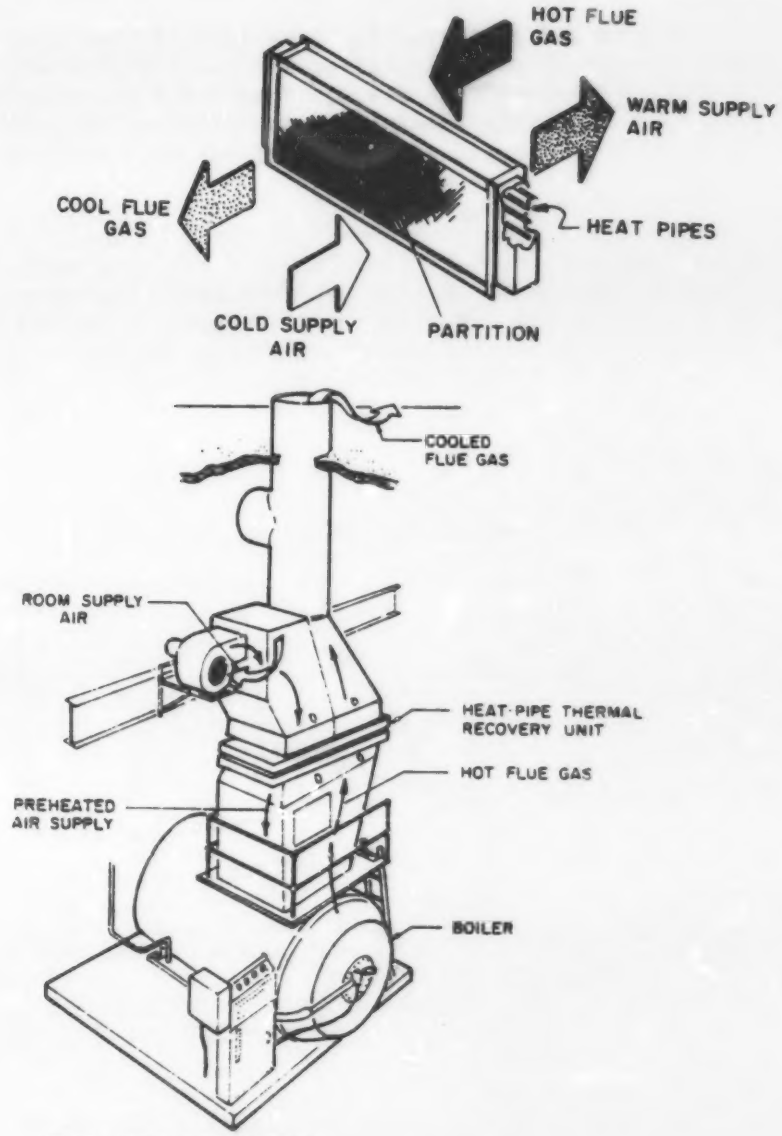
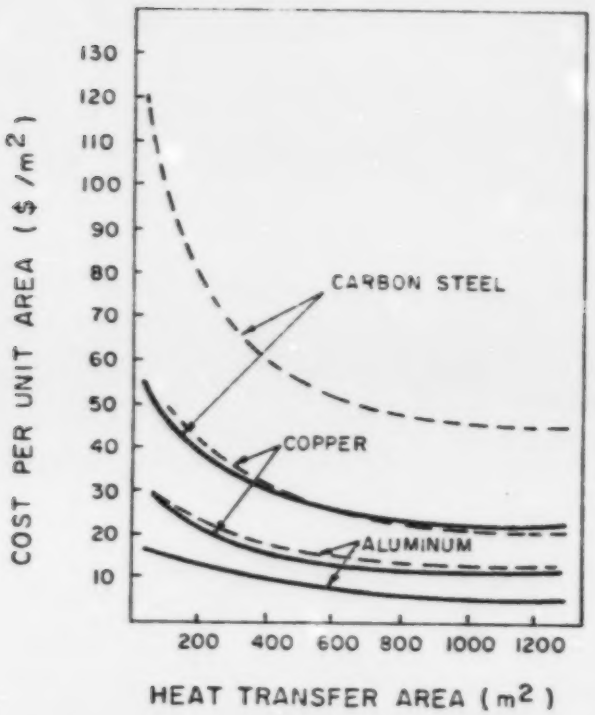


FIGURE 2.5. HEAT-PIPE EXCHANGER

Cost data for a variety of heat pipe exchangers of different sizes and construction materials is given in Figure 2.6. Total capital cost including equipment cost and installation cost is also shown. Costs are expressed per unit surface area of the heat exchanger.



——— EQUIPMENT COST

- - - - - - - - TOTAL CAPITAL COST (Including Equipment Cost and Installation Cost.)

FIGURE 2.6. COSTS OF HEAT-PIPE HEAT EXCHANGERS AS A FUNCTION OF SIZE AND CONSTRUCTION MATERIALS [1]

Rotary heat-exchangers. Rotary heat exchangers (sometimes called heat wheels) were invented over 50 years ago and have been used in numerous HVAC and industrial heat recovery installations.

As shown in Figure 2.7. a rotary heat exchanger consists of a rotary core approximately 0.3 m (1 ft) thick and 1 to 3.5 m (3 to 12 ft) in diameter containing heat transfer medium. The core rotates in a casing between the supply air and flue gas with the respective streams normally flowing in opposite directions. The wheel absorbs heat from the flue gas and transfers it to the supply air stream.

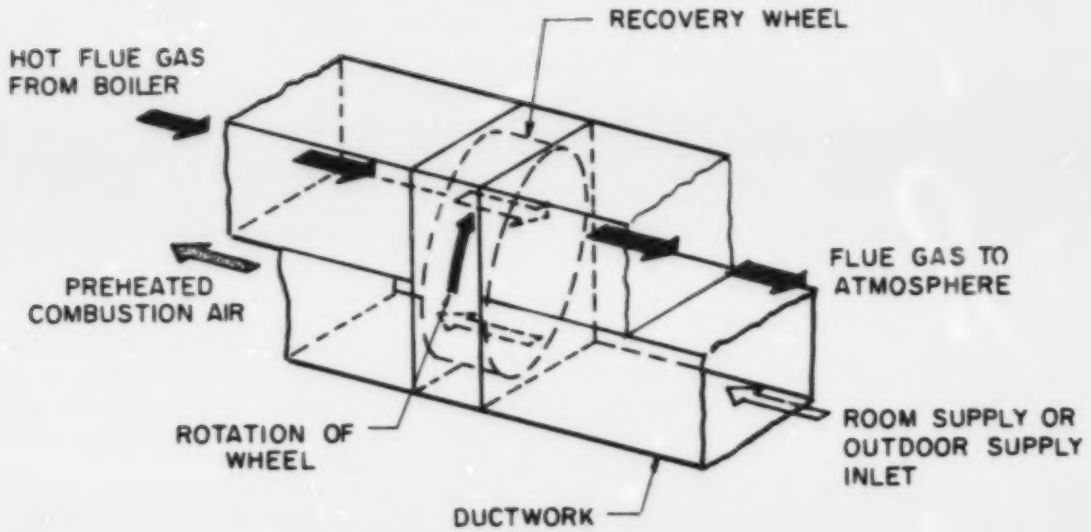


FIGURE 2.7. ROTARY AIR PREHEATER

For the application of flue gas heat recovery, metallic heat transfer media are commonly used. Approximate capacity range and maximum operating flue-gas temperature for metallic heat wheels are summarized in Table 2.2. [2].

TABLE 2.2. CAPACITY RANGE AND MAXIMUM OPERATING TEMPERATURE FOR VARIOUS METALLIC HEAT WHEELS

Heat Wheel Media	Capacity Range (L/s)	(scfm)	Max. Temperature (C)	(F)
Stainless Steel Mesh	350 to 34 000	750 to 72 000	300	600
Corrugated Aluminized Steel	350 to 34 000	750 to 72 000	300	600
Corrugated Low Alloy Steel	200 to 22 000	400 to 44 000	400	750

The thermal efficiency of heat wheels is usually higher than other air-to-air heat exchangers and typically ranges from 60 to 80% depending on the installation, type of wheel and mass-flow rates employed.

Packaged units are commercially available from a host of manufacturers. The basic unit contains a heat recovery wheel, supply and exhaust fans, filters, dampers and a control package. Equipment manufacturers suggested that typical equipment costs are $2 000 to $3 000 per 500 L/s (1 000 scfm). Installation costs typically range from 70 to 100% of the equipment costs.

Plate type heat exchangers. These heat exchangers are built up as a sandwich of thin parallel plates (Figure 2.8.). Flue gas passes through alternate passages, while cold supply air passes through adjacent passages in a counter-current direction. Heat is transferred from the hot stream to the cold stream by conduction through the parallel plates.

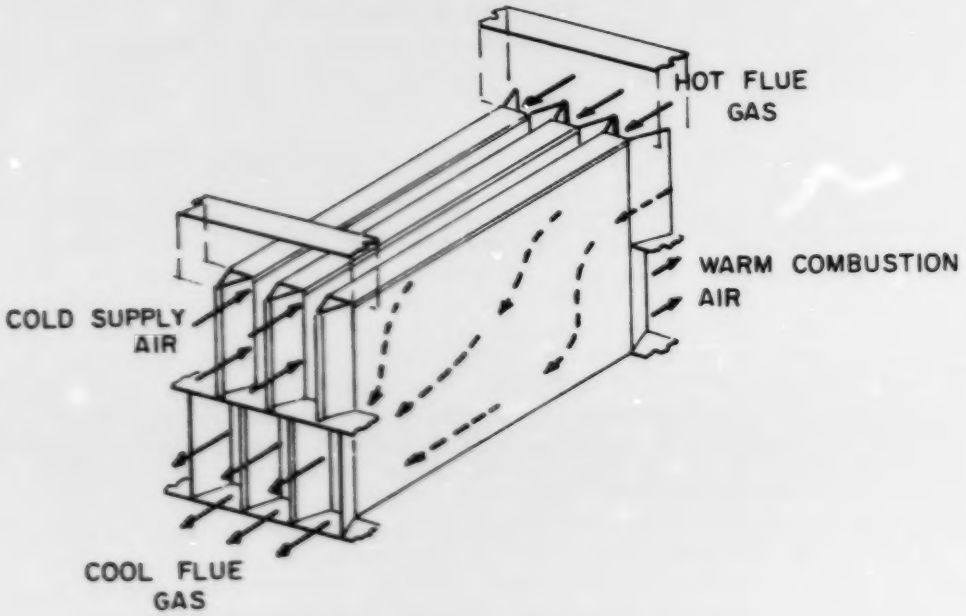


FIGURE 2.8. PARALLEL-PLATE AIR PREHEATER

Heat exchangers with plate-fin arrangement are also commercially available. One advantage of this type is the compactness of the unit. In addition, various techniques are employed by the heat exchanger industry to produce high-performance surfaces. One of the most widely used methods is to interrupt the wall surfaces so that the boundary layer thickness is minimized. Other methods, such as the use of curved or wavy passages, are also utilized.

Plate type heat exchangers are fabricated from various steel alloys for applications up to 870 C (1 600 F).

Typical rated efficiency of this type of heat exchanger for flue gas heat recovery is in the 50 to 60% range. Equipment costs are $2 000 to $3 000 per 500 L/s (1 000 scfm) of flue gas flow. Installation may cost as much as 100 percent of the equipment costs.

2.2. Material Selection - Effect of Sulphur

Natural gas and fuel oils contain sulphur. During the combustion process, hydrogen and carbon in the fuel are rapidly oxidized to give off heat. Sulphur present in the fuel will combine with oxygen to form sulphur dioxide (SO_2). Depending on the sulphur content of the fuel, the amount of excess air and flame temperature, some sulphur dioxide may be further oxidized into sulphur trioxide (SO_3). It is these sulphur oxides in the flue gas that create the largest potential for corrosion. Sulphur dioxide combines with water to form sulphurous acid (H_2SO_3). Sulphur trioxide can combine with water vapour to form sulphuric acid (H_2SO_4). The former occurs at a temperature known as the water dew point and the latter occurs at what is known as the "acid dew point". The water dew point and acid dew point of flue gases formed from fuels with various sulphur concentrations are shown in Figure 2.9. [3].

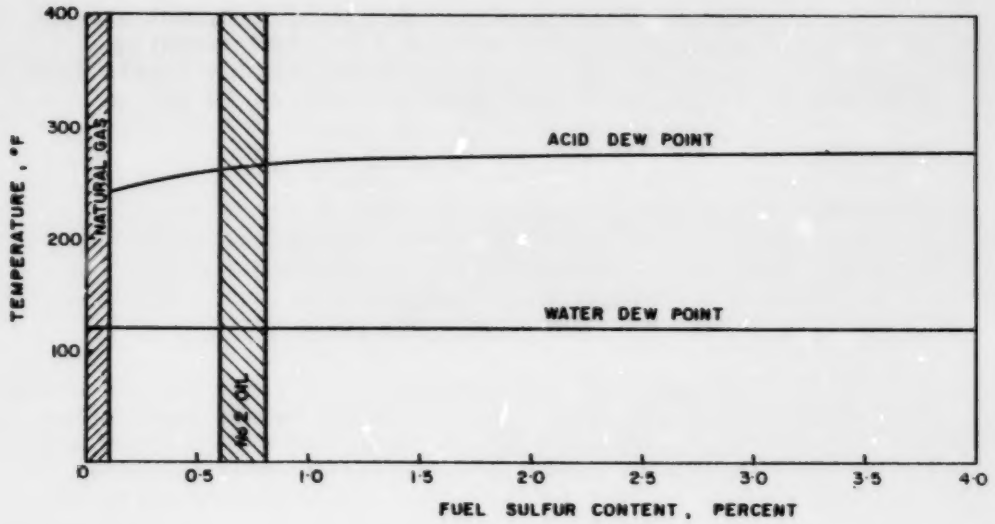


FIGURE 2.9. ACID DEW POINT AND WATER DEW POINT vs FUEL SULPHUR CONTENT (source: Kentube Ltd.)

It has been common to avoid acidic corrosion by ensuring that all parts of the heat exchanger are maintained at temperatures above the acid dew point of flue gases. With increasing fuel costs it has become necessary for building owners to increase the efficiency of the fuel-burning equipment. This leads to reduced flue-gas temperature which, however, requires heat exchangers to be fabricated from materials more resistant to corrosion.

If the flue-gas temperature is lower than the acid dew point, the use of heat exchanger materials which will withstand condensate corrosion is required. A wide variety of materials, including ferrous and non-ferrous metals, alloys, ceramic-type coatings, etc., has been tested to determine their ability to withstand this type of exposure [4, 5, 6, 7]. The results show that suitable corrosion-resistant and

durable materials for condensing equipment are the stainless steels 316 and 304. Teflon-coated surfaces may also prove acceptable but little data is presently available on longevity of teflon coatings for this application.

2.3 Market Penetration

2.3.1 Finned-Tube Economizers

Finned-tube heat exchangers for water heating appear to have a good opportunity for market penetration. The units are compact and do not occupy floor area. Equipment installation costs are also relatively low, generally within the range of $800 to $1 000 per unit. Typically, the investment pay-back period is two to four years.

Despite the attractiveness, our survey indicated that only a small number of units are installed in apartment and office buildings. One heat exchanger supplier attributed this to an inability to obtain certification of the product from the Canadian Gas Association and Canadian Standards Association. To overcome this problem, a standard for installation of air-to-liquid type flue gas heat reclaimers was recently released by the Ontario Ministry of Consumer and Commercial Relations. According to this new standard, such a heat reclaimer does not require certification if it is used in conjunction with a certified gas or propane fired appliance equipped with an externally mounted draft hood.

2.3.2 Flue-Gas-To-Air Heat Reclaimers

A variety of heat reclaimers are readily available for flue-gas heat recovery. A brief survey indicated that flue-gas-to-air heat exchangers are quite common in industrial plants. Nevertheless, they are seldom installed in office and apartment buildings. Presently it appears that wide acceptance is inhibited due to the large amount of duct work required. The duct work is costly and very often there is insufficient space available in existing buildings. In addition, major burner modifications are sometimes required in order to accept preheated combustion air. These appear to represent significant barriers to the application of flue-gas-to-air heat reclaimers for combustion air preheating in office and apartment buildings.

2.3.3 Condensing Flue-Gas Heat Reclaimers

Condensing type flue-gas heat recovery systems are commonly available in Europe [8], but have only recently been marketed in North America. A Canadian water heater manufacturer, A.O. Smith Limited, initiated marketing of packed-bed heat reclaimers several years ago. The company has discontinued production temporarily, but is expected to re-enter the market in the future.

In Canada there are several condensing flue-gas heat reclaimers installed in industrial plants, but there are no known installations in offices or apartment buildings. High capital costs appear to be the main reason against using condensing flue-gas heat reclaimers.

This section presents some general financial analysis techniques which can assist building owners and designers in evaluating the economic attractiveness of investments in flue-gas heat recovery.

The methods described here are used for the economic analysis examples given in section 3.3.

3.1 Nomenclature Used

CC: Capital Cost - This item is the capital cost of the investment, including the equipment and installation costs.

PFP: Projected Fuel Price - The PFP is the estimated average fuel price over the life time of the investment, which under the present economic conditions is very difficult to assess. In most cases, the assumption used is that the fuel cost for the next 10 years will increase at an annual rate of 15%.

EL: Estimated Life - EL is the useful life expectancy of the heat recovery unit.

AOC: Annual Operating Cost - AOC is the annual average of costs associated with maintaining and operating the installed heat recovery system. This item can be estimated with assistance from the equipment supplier.

AFS: Annual Fuel Savings - This item is simply the annual fuel cost reduction achieved by installation of the heat recovery system. In order to establish a value for this item, the measured performance of the existing system and either the measured or predicted performance of the installed system must be made. The overall efficiency of fuel-burning equipment can be determined precisely only by laboratory test under controlled conditions. However, a simple method is available to allow for calculation of the approximate but realistic efficiency based on the steady-state flue-gas temperature in the stack, combustion air temperature and percentage of excess air for combustion. From these parameters the steady-state thermal efficiency can be determined using Figures 3.1. and 3.2. for natural gas and oil fired equipment respectively. An additional 3% should be discounted for radiation loss from the heating plant. A comparison of these performance values using the nomograph of Figure 3.3. allows the fuel savings to be determined.

NAS: Net Annual Savings - NAS is the annual average of fuel savings after discounting the annual operating cost (AOC).

NFS: Net First Year Savings - The NFS is the first year fuel savings after considering operating cost.

EDC: Equipment Depreciation Cost - EDC is the annual depreciation of the investment. Straight line depreciation method CC/EL is used in this analysis.

DR: Discount Rate - The discount rate is the interest rate paid by the investor to finance the project.

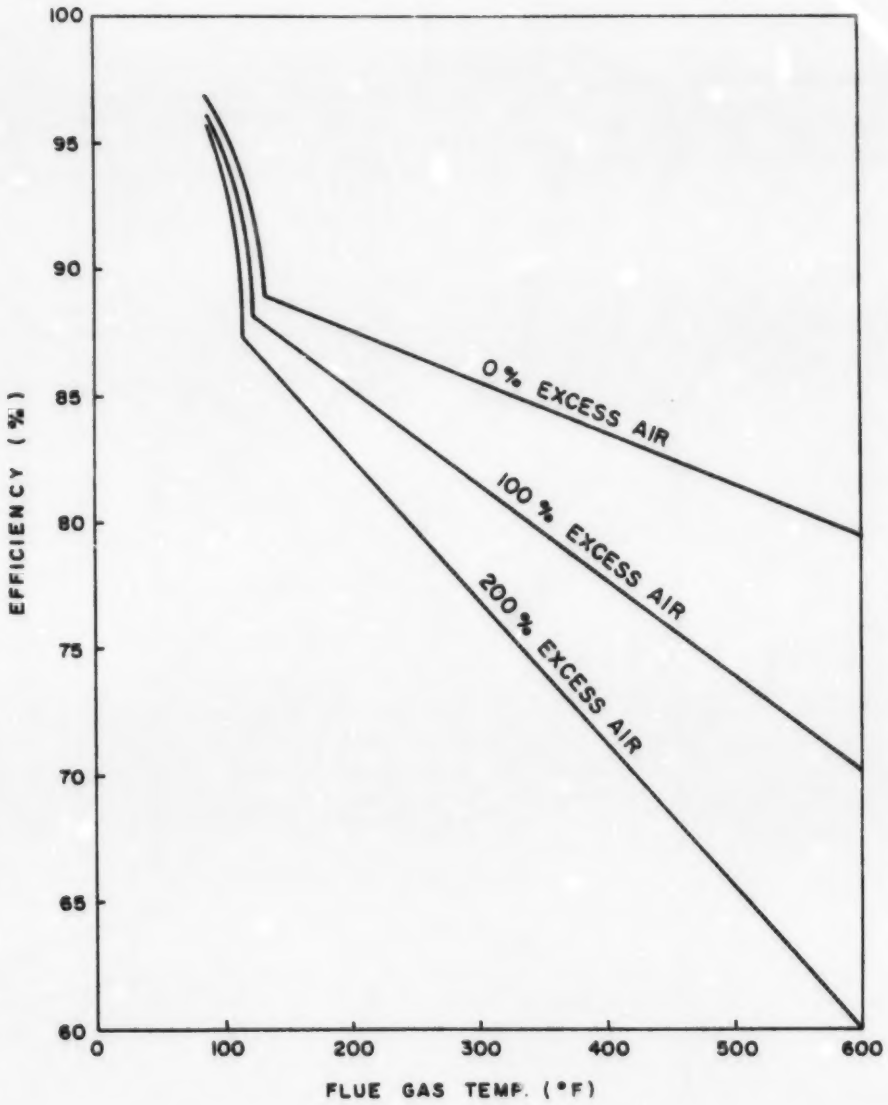


FIGURE 3.1. EFFICIENCY OF NATURAL GAS-FIRED EQUIPMENT

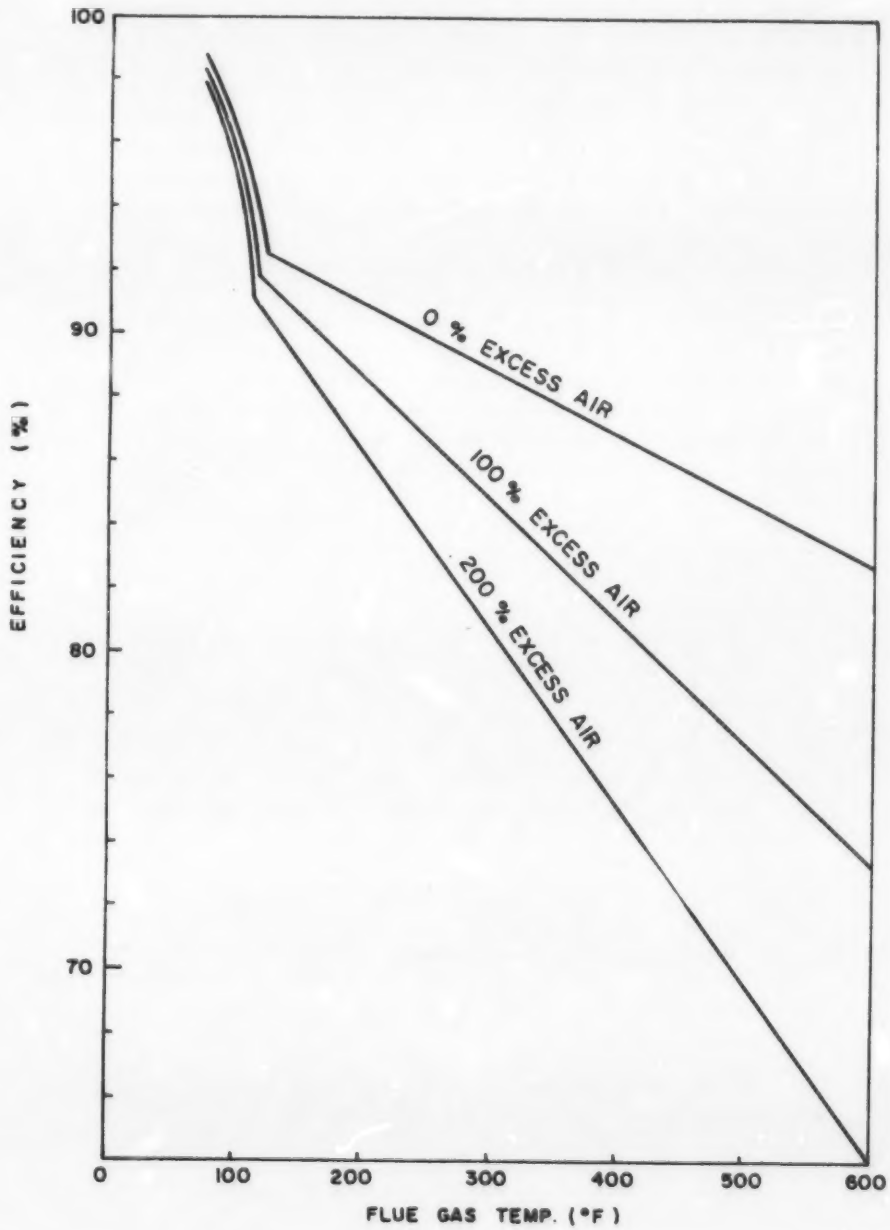


FIGURE 3.2. EFFICIENCY OF OIL-FIRED EQUIPMENT

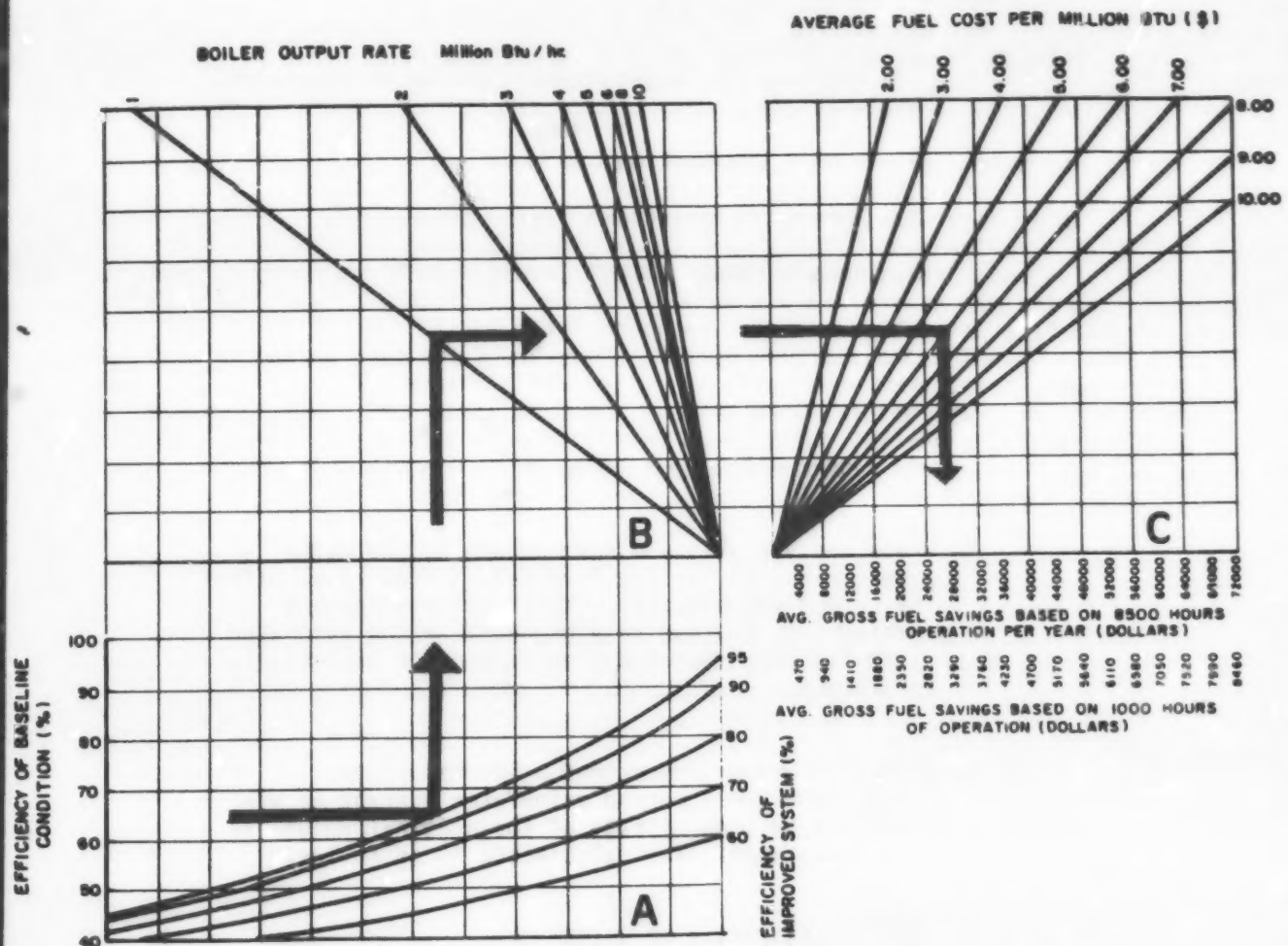


FIGURE 3.3. CHART/NOMOGRAPH FOR GROSS FUEL SAVING PROJECTION

3.2 Investment Analysis

The most popular methods used to make an investment analysis are:

1. Simple pay-back method
2. Return on investment
3. Benefit/cost ratio

PP: Payback Period - The simple pay-back period is defined by:

$$PP = CC / NFS$$

This measure allows one to determine the number of years required for the invested capital to be offset by resulting benefits. Usually if the payback period (PP) is less than one-half of the estimated life (EL) the investment is considered potentially profitable.

ROI: Return on Investment - The return on investment (ROI) method calculates average annual benefits as a percentage of the original value of the investment. The calculation is as follows:

$$ROI = (NFS-EDC) / CC \times 100\%$$

In general, a 20 percent return before income taxes would be the minimum acceptable return for business investments.

These methods can to be used as simple indicators for screening possible energy conservation opportunities but the third method may be required on major investments.

B/C: Benefit/Cost Ratio - The principle of this procedure is that the future cash flow is increasingly reduced in value for each year at a given discount rate. For energy conservation investments, the discount rate represents the rate at which the building owners can obtain capital to finance the investment. There are several analysis techniques which utilize this concept. The Benefit/Cost Ratio (B/C) is the most popular one. In this method a Present Worth Factor (PWF) is defined such that Present Value (PV) of all future savings is calculated as follows:

$$PV = PWF \times NAS$$

The PWF is a function of both the discount rate and the estimated life (EL). Table 3.1. is provided to summarize this functional relationship.

The benefit/cost ratio (B/C) is then given by:

$$B/C = \frac{\text{present value of all future savings}}{\text{capital cost}}$$

$$= \frac{PV}{CC}$$

The predicted benefit/cost ratio (B/C) must be greater than unity before capital investment in the project is given consideration.

TABLE 3.1. PRESENT WORTH FACTORS (PWF)

Lifetime (EL)	Discount Rate				
	5%	10%	15%	20%	25%
1	0.952	0.909	0.870	0.833	0.800
2	1.859	1.736	1.626	1.528	1.440
3	2.723	2.487	2.283	2.106	1.952
4	3.546	3.170	2.855	2.589	2.362
5	4.329	3.791	3.352	2.991	2.689
6	5.076	4.355	3.784	3.326	2.951
7	5.786	4.868	4.160	3.605	3.161
8	6.463	5.335	4.487	3.837	3.329
9	7.108	5.759	4.772	4.031	3.463
10	7.722	6.145	5.019	4.192	3.571
11	8.306	6.495	5.234	4.327	3.656
12	8.863	6.814	5.421	4.439	3.725
13	9.394	7.103	5.583	4.533	3.780
14	9.899	7.367	5.724	4.611	3.824
15	10.380	7.606	5.847	4.675	3.859
16	10.838	7.824	5.954	4.730	3.887
17	11.274	8.022	6.047	4.775	3.910
18	11.690	8.201	6.128	4.812	3.928
19	12.085	8.365	6.198	4.843	3.942
20	12.462	8.514	6.259	4.870	3.954
21	12.821	8.649	6.312	4.891	3.963
22	13.163	8.772	6.359	4.909	3.970
23	13.489	8.883	6.399	4.925	3.976
24	13.799	8.985	6.434	4.937	3.981
25	14.094	9.077	6.464	4.948	3.985

It should be noted that the above calculations do not take into account the advantages offered by applicable Federal and Provincial government tax incentive programs, briefly discussed in Section 4.2.

3.3 Economic Analysis Examples

The following provides examples demonstrating the economic analysis procedures described in the preceding section.

In order to provide realistic data for this study, site visits were made to two office buildings in Toronto and boiler operating parameters were measured.

Case A

An office building in Toronto uses two hot water boilers with a rating of 3 097 kW (10.57 MM BTU per hour) to provide heat for space heating. The boilers are fired with natural gas and have a stack temperature of 255 C (491 F). The measured excess air is 39%. The main parameters of the boilers are given in Table 3.2.

An energy conservation opportunity exists to recover energy from the flue gas for water pre-heating in a finned-tube heat exchanger. It is desirable to maintain the flue gas exit temperature at or above 121 C (250 F) to prevent heat exchanger corrosion.

Discussions with a heat exchanger manufacturer revealed that the heat reclaimer required for this application has a capital cost (CC) of $13 800 (equipment cost = $13 000; installation cost = $800). The specification of the unit is given in Table 3.3. The annual operation charge (AOC) is about $500 which includes maintenance charge and pump power cost. The estimated life (EL) of the equipment is 10 years.

TABLE 3.2. BOILER OPERATING DATA FOR CASE A

BOILER SPECIFICATIONS

BOILER TYPE	:	Inglis
MODEL No.	:	S2400
SERIAL No.	:	8231
MAX. FIRING RATE	:	
BURNER TYPE	:	Power, Modulating, Dual Fuel Burner
	:	Natural Gas

TEST DATA

FLUE GAS TEMPERATURE (^{o}F)	:	255^{o}C (491^{o}F)
BOILER ROOM TEMPERATURE (^{o}F)	:	DRY BULB _____ WET BULB _____
ATMOSPHERIC PRESSURE (IN. Hg.)	:	
FUEL FLOW RATE (GAS)	:	
BOILER INPUT RATE	:	3097 kW (10.576 x 10.^{6} Btu/Hr.)

FLUE GAS ANALYSIS

OXYGEN (O_2)	%:	6.3
CARBON DIOXIDE (CO_2)	%:	8.0
CARBON MONOXIDE (CO)	%:	
EXCESS AIR	%:	39%

EFFICIENCY CALCULATIONS

EFFICIENCY FROM FIGURE 11	:	79 %
RADIATION LOSS	:	3 %
OVERALL EFFICIENCY	:	76 %

OTHER DATA

INLET WATER TEMPERATURE	:	49^{o}C (120^{o}F)
ANNUAL FUEL CONSUMPTION PER BOILER	:	0.635 x 10^{6} m^{3} (22500 Mcf) per unit
UTILIZATION LEVEL	:	2127 hours

TABLE 3.3. HEAT RECLAIMER SPECIFICATIONS FOR CASE A

Operating Parameters of the Heat Reclaimer:		
Flue-gas exit temperature	-	250 F
Flow capacity	-	36 gallons/min
Entering-water temperature	-	120 F
Temperature rise	-	47.8 F
Gas-side pressure drop	-	0.2199 inches of water column
Water-side pressure drop	-	3.67 foot head
Manufacturer's Recommended Heat Reclaimer:		
Model	-	140-24
Height	-	47 inches
Width	-	39.5 inches
Length	-	45 inches
Shipping weight	-	980 pounds

Source: Therma-Stack Canada Ltd. quotation.

The steady-state efficiency of the boiler at baseline condition is 76%. From Figure 3.1., the efficiency for the improved system is 82.5%. The first year fuel price is $4 per 293 kWH (1 MM BTU) and the projected average fuel cost over the ten year period is $9.50 per 293 kW (1 MM BTU). The discount rate (D) is assumed to be 18%.

From Figure 3.3., during the first year of operation the saving on fuel cost is $3 200 per 1 000 hours or $6 806 based on 2 127 operation hours per year.

The economic data is summarized as follows:

1. Capital Cost (CC) = $13 800

2. Annual Operation Charge (AOC) = $500

3. Estimated Life (EL) = 10 years

4. Net First Year Saving (NFS) = $6 806 - $500
   = $6 306

5. Annual Fuel Saving (AFS) =$6 806 x 9.5 / 4
   = $14 977

6. Net Annual Fuel Saving (NAS) = $14 977 - $500
   = $14 477

(i) Simple Payback Period (PP)

PP = CC / NFS

= 13 800 / 6 306

= 2.2 years

This indicates a very good investment with a short pay-back period.

(ii) Return on Investment (ROI)
Equipment Depreciation Charge (EDC)

EDC = CC / EL

= $13 800 / 10

= $1 380 / year

ROI = (NFS - EDC) / CC x 100%

= (6 306 - 1 380)/ 13 800 x 100%

= 36%

This is well above the normal acceptable rate of 20%.

(iii) Benefit/Cost Ratio (B/C)

From Table 3.1. for a discount rate of 18% and expected life of 10 years, the Present Worth Factor (PWF) = 4.52

PV = NAS x PWF

= $14 477 x 4.52

= $65 436

B/C = PV / CC

= $65 436 / $13 800

= 4.7

Again, this indicates an extremely attractive opportunity for invesment, with "benefits" versus "costs" of the order of 4 to 1.

If a condensing type heat exchanger is used, the following economic data can be summarized as follows:

1. Capital Cost (CC) = $45 000

2. Annual Operation Charge (AOC) = $1 000

3. Estimated Life (EL) = 10 years

4. Net First Year Saving (NFS) = $12 000 - $1 000
   = $11 000

5. Annual Fuel Saving (AFS) = $12 000 x 9.5 / 4
   = $28 500

6. Net Annual Fuel Saving (NAS) = $28 500 - $1 000
   = $27 500

(i) Simple payback period (PP)

PP = CC / NFS

= 45 000 / 11 000

= 4.1 years

(ii) Return on Investment (ROI)

Equipment Depreciation Charge (EDC)

= CC / EL

= $45 000 / 10

= $4 500 / year

ROI = (NFS - EDC) / CC x 100%

= (11 000 - 4 500) / 45 000 x 100%

= 14.4%

(iii) Benefit/Cost Ratio (B/C)

From Table 1 for a discount rate of 18% and expected life of 10 years, the Present Worth Factor (PWF) = 4.52

PV = NAS x PWF

= $27 500 x 4.52

= $124 300

B/C = PV / CC

= $124 300 / $45 000

= 2.76

The economic analysis indicates that a condensing heat exchanger is not an attractive investment because the ROI is less than 20%.

Case B

Case B is similar to Case A. It relates to an office building in Toronto which employs six hot water boilers each of 49 kW (1.67 MM Btu/hr) capacity. The main parameters of the boilers are given in Table 3.4.

It is proposed to install an economizer on each boiler to recover energy from the flue gas for hot water preheat. The capital cost (CC) for each economizer is $5 191 (equipment cost = $4 391, installation cost = $800). The main design parameters of the heat exchanger are given in Table 3.5.

Using the procedures illustrated above, the economic data can be summarized as follows:

1. CC = $5 191
2. AOC = $500
3. EL = 10 years
4. NFS = $1 616 - $500 = $1 116
5. AFS = $1 616 x 9.5 / 4 = $3 838
6. NAS = $3 838 - $500 = $3 338

(i) Pay-back period (PP)

PP = CC / NFS = $5 191 / $1 116 = 4.65 years

(ii) Return on Investment

EDC = $5 191 / 10

= $519 / year

ROI = (NFS-EDC) / CC x 100%

= (1 116 - $519) / 5 191 x 100%

= 11%

TABLE 3.4. BOILER OPERATING DATA FOR CASE B

BOILER SPECIFICATIONS

BOILER TYPE	:	Teledyne Laars
MODEL No.	:	HB 3000
SERIAL No.	:	1740155
MAX. FIRING RATE	:	
BURNER TYPE	:	Atmospheric Burner
	:	Natural Gas

TEST DATA

FLUE GAS TEMPERATURE (^{o}F)	:	288°C (550°F)
BOILER ROOM TEMPERATURE (^{o}F)	:	DRY BULB _____ WET BULB _____
ATMOSPHERIC PRESSURE (In.Hg.)	:	
FUEL FLOW RATE OIL (or GAS)	:	
BOILER INPUT RATE (BUT/HR)	:	490 kW (1.67 x 10^6 Btu/Hr.)

FLUE GAS ANALYSIS

OXYGEN (O_2)	% :	11.5
CARBON DIOXIDE (CO_2)	% :	5.2
CARBON MONOXIDE (CO)	% :	
EXCESS AIR	% :	113.3

EFFICIENCY CALCULATIONS

EFFICIENCY FROM FIGURE 11:		71.25 %
RADI ATION LOSS	:	3 %
OVERALL EFFICIENCY	:	68.25 %

OTHER DATA

INLET WATER TEMPERATURE	:	46° C (115°F)
ANNUAL FUEL CONSUMPTION	:	81349 m^3 (2872 Mcf) per unit
UTILIZATION LEVEL	:	1720 Hours

TABLE 3.5. HEAT RECLAIMER SPECIFICATIONS FOR CASE B

Operating Parameters of the Heat Reclaimer:		
Flue-gas exit temperature	-	265 F
Flow capacity	-	36 gallons/min
Entering-water temperature	-	115 F
Temperature rise	-	19.02
Gas-side pressure drop	-	0.0114 inches of water column
Water-side pressure drop	-	0.92 foot head
Manufacturer's Recommended Heat Reclaimer:		
Model	-	48-24
Height	-	32 inches
Width	-	33.5 inches
Length	-	40 inches
Shipping weight	-	260 pounds

Source: Therma-Stak Canada Ltd. quotation.

(iii) Benefit/Cost Ratio (B/C)

From Table 3.1., for a discount rate of 18% and equipment expected life of 10 years, the Present Worth Factor (PWF) = 4.52

PV = NAS x PWF

= $3 338 x 4.52

= $15 087

B/C = PV/CC

= $15 087 / $5 191

= 2.9

This economic analysis indicates that Case B is a marginal investment. The relatively small boiler size and the low utilization level of the boilers are the contributing factors.

3.4 Case Study for Flue-Gas Heat Recovery

Description: A site visit was made to an apartment building in North York, Toronto. The 15 storey building and a nearby shopping plaza were heated by 16 gas-fired boilers. Each boiler had an input rate of 670 000 Btu/hr and was equipped with an atmospheric burner.

Action Taken: As shown in Figure 3.4., finned-tube economizers supplied by Therma-Stack Canada Limited were installed on 6 boilers to recover energy from boiler flue-gas by dropping the flue-gas temperature from 270 C (520 F) to 138 C (280 F).

Cost for Improvement: $18 000

Annual Fuel Saving: Therma-Stack Canada Limited claimed that the annual fuel saving was approximately $8 000, resulting in a simple pay-back period of approximately 2.5 years.

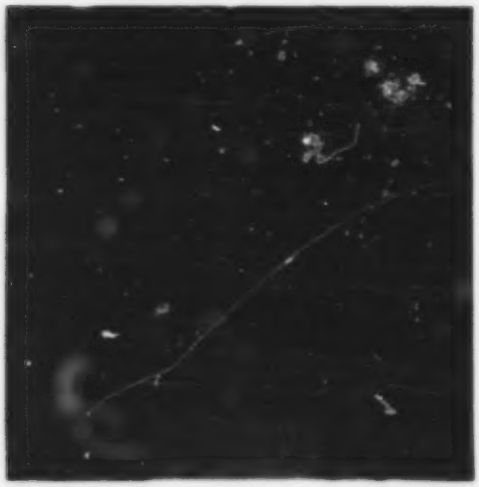


FIGURE 3.4. AN INSTALLATION OF FLUE-GAS HEAT RECLAIMERS IN AN APARTMENT BUILDING

4.1. Codes and Standards

A review of applicable codes, standards and regulations was undertaken to investigate whether there are any barriers to wide scale implementation of flue-gas heat recovery technologies described in this report.

Existing installation codes [9] in Canada for oil burning equipment require heat reclaimers to be certified by a recognized testing agency. The code also outlines information which should be included in the manufacturer's installation instructions. Typical information relating to the type and size, minimum draft requirement after installation and detailed installation instructions (including minimum clearances to combustible materials) should be provided by the manufacturer. Condensing units are permitted when adequate provisions are made for the effects of condensation.

The Canadian national installation code for natural gas burning equipment, CAN 1-B 149.2-78 [10], does not specifically address installation of flue-gas heat reclaimers. However, the Ontario Ministry of Consumer and Commercial Relations has released a standard, G/P No. 2, which outlines requirements applicable to the installation, operation and maintenance of an air-to-liquid heat reclaimer installed in a natural gas or propane fired system [11]. The standard does not require heat reclaimers to be certified. No other provinces in Canada have issued standards.

If condensing heat reclaimers are used, the condensate produced from the flue gas must receive chemical treatment to increase its pH value to an acceptable level before it is discharged into the public sewage system. Municipal regulatory agencies throughout Canada have their own by-laws to regulate the discharge of sewage. Acceptable pH values for major Canadian cities are given in Table 4.1.

TABLE 4.1. ACCEPTABLE PH LEVELS OF WATER TO BE DISCHARGED INTO SEWAGE SYSTEMS

CITY	ACCEPTABLE PH LEVELS	BY-LAW NO.
Saint John, N.B.	6.0 to 9.5	21 Section E
Montreal, Quebec	6.5 to 8.5	Provincial
Toronto, Ontario	5.5 to 10.5	2520
Winnipeg, Manitoba	5.5 to 9.0	505.73
Regina, Saskatchewan	5.0 to 9.0	5601
Edmonton, Alberta	5.5 to 12.0	3875
Vancouver, B.C.	5.5 to 9.5	5320

4.2. Government Incentives

The Canadian Federal Government offers incentive programs that allow an accelerated capital cost allowance designed to encourage business and industry to reduce energy waste, to decrease dependence on oil and to convert to renewable energy sources. Simply stated, this provision allows a "fast write-off" which applies to machinery and equipment which form part of a system as listed in Class 34 of the Income Tax Regulations.

Heat recovery equipment described in this report qualify for such incentive programs. Appendix II gives a brief outline of these programs.

Building owners and managers could also check with their provincial government agencies regarding any applicable incentive programs that would improve the cost/benefit ratio of their proposed flue-gas heat recovery projects.

5.1 General

Conventional heating plants used for providing domestic hot water and space heating in buildings generate flue-gas at temperatures up to 315 C (600 F). An opportunity exists to recover energy from the flue-gas with heat exchangers. The reclaimed energy can be used for water heating. In general, a 5 to 15% energy savings appears realistic.

5.2 Technology

Findings of this study show that flue-gas heat recovery technologies suitable for apartment and office buildings are readily available and can assist building owners in achieving lower fuel consumption.

Finned tube flue-gas-to-water type economizers are most suitable for this application. They have a relatively short pay-back period and can be easily installed.

Condensing type flue-gas heat reclaimers have a potential for substantial energy savings. However, the high capital costs presently make them unattractive.

5.3 Economic Considerations

Nearly every building owner would save energy by installing flue-gas heat recovery systems in his building. But in some cases, the energy saved would not pay for the investment. Therefore, an investment analysis procedure has been provided in this report to demonstrate techniques which can be used to evaluate the economic attractiveness of energy conservation investments using different criteria: the pay-back period, the rate of return on investment, and the benefit/cost ratio.

As a rule of thumb, investments in finned-tube economizers are generally profitable when the following conditions are met:

- Individual boiler capacity: 150 kW (0.5 MM Btu/hr) or larger
- Flue gas temperature: 260 C (500 F) or higher
- Annual Boiler Utilization: 2 000 hr or more
- The boiler has no internal flue dilution device (i.e. draft hood).

5.4 Codes and Standards

There appear to be no major barriers which inhibit the use of flue-gas heat reclaimers in apartment or office buildings. However, if condensing-type heat exchangers are used, chemical treatment of condensate is required to increase its pH value to an acceptable level. In general, the lowest pH value allowed in major Canadian cities is 5.5.

This study has indicated that potential exists for substantial energy savings by application of flue-gas heat recovery technology in offices and apartment buildings.

It is recommended that information on current technology be made available to building owners. Particular attention should be paid to building owners with small holdings who normally have little technical support.

A further recommendation is that a small number of office and apartment buildings be selected for retrofit of various types of flue-gas heat recovery units. These demonstration buildings could be monitored to obtain more detailed information relating to actual savings and costs associated with flue-gas heat recovery equipment.

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2. Pamboke, T. "Air-to-Air Energy Recovery" Heating/Piping/Air Conditioning March 1976, Page 37.

3. Troudt, V., "Economizer: Beauty or Beast", Heating/Piping/ Air Conditioning, August, 1979.

4. Schaw, O.O., and Lahtrec, T., "Study of Materials to Resist Corrosion in Condensing Gas-Fired Equipment", Symposium on Condensing Heat Exchangers, Atlanta, March, 1982.

5. DeWerth, D.W., amd Watery, A.M., "Effect of Flue-Gas Condensate on Heat Exchanger Materials of Construction", Symposia on Condensing Heat Exchangers, Atlanta, March, 1982.

6. White, E.L., Bell, D.A.,and Lux, Jr. J.J., "Materials Evaluation for Oil-Fired Condensing Furnaces and Boilers", Symposia on Condensing Heat Exchangers, Atlanta, March, 1982.

7. Messen, R., "Condensing Heat Exchangers Using Teflon-Coated Tubes", Symposia on Condensing Heat Exchangers, Atlanta, March, 1982.

8. Thompson, R., et al. "A Survey of Flue-Gas Condensation Heat Recovery for Industrial Boilers", Symposium on Condensing Heat Exchangers, Atlanta, 1982.

9. "Installation Code for Oil Burning Equipment" Canadian Standards Association, CSA Standard B139-1976.

10. "Installation Code for Natural Gas Burning Equipment" B149-1-78.

11. Ontario Ministry of Consumer and Commercial Relations, Preliminary Standard G/P No. 2, "Installation, Operation and Maintenance Standard for an Air-to-Liquid Type Heat Reclaimer", January, 1982.

12. Peters and Timmerhaus "Plant Design and Economics for Chemical Engineers" Third Edition McGraw Hill.

13. Gratta, R., Massey, R., and Robertson, J.C., "Financial Evaluation Procedures", Energy Conservation Program Guide for Industry and Commerce, U.S. National Bureau of Standards, 1974.

14. American Gas Association, "Fact Sheet - Condensate Removal from Condensing Appliances".

List of Organizations Contacted

I.1. Equipment Manufacturers and Suppliers

Mr. G.F. Pick
Manager, Canadian Operation
A.O. Smith Limited
768 Erie Street
Stratford, Ontario
N5A 2E3

Mr. D.B. Plotter
I.P.E. Limited
(Associates Granco International Ltd.)
158 Kennedy Road S.
Brampton, Ontario
L6W 3G7

Mr. R.A. Hogsden
Indusco Limited
48 Channcey Avenue
Toronto, Ontario
M8Z 2Z4

Mr. J.J. Paulin
Vice President
Preston, Phipps Limited
940 Osilvy Avenue
Montreal, Quebec
H3N 1P4

Mr. Pennetier
Material Thermique et Chaudronnerie Union
72 Ave. J.-B. Clement
92100 Boulogne-Billancourt
France
Tel: 604-81-18

Keeprite Inc.
150 Consumers Road
Suite 302
Willowdale, Ontario
M2J 1P9

Thermogenics Limited
311 Rowes Road
Concord, Ontario
L4K 1R1

D-Dot Corporation
726 Regal Row
Dallas, Texas 75247
Tel: (214) 630-1224

Mr. G. Eagleson
President
Therma-Stack Canada Limited
Suite 232
Scarborough, Ontario
M1R 4B9

Reckett Heat Recovery Systems
100 Grantham Avenue
St. Catherines, Ontario
L2R 7B9

Enco 2000 Inc.
1311 Johnson Ferry Road
Suite 272
Marietta, GA. 30067
(404) 971-9007

Mr. R.K. Wilkinson
Canadian Boilers Limited
6853-B, Airport Road
Mississauga, Ontario
L4V 1E6

I.2. Consulting Firms

Dr. Dominique Noir
Battelle
Geneva Research Centre
7 Route de Drize
1227 Garouge
Geneva, Switzerland
(022) 43-98-31

Mr. Laurie Nichols
CMA Chalifour, Marcotte et Associes Inc.
83 Place Frontenac
Pointe Claire, Quebec

Mr. R.E. Thompson
Manager, Research and Analysis Div.
KVB Limited
18006 Skypark Blvd.
Irvine, CA 9271
USA

Mr. K.T. Feldman Jr.
Energy Engineering Inc.
Albuquerque, N.M.
U.S.A.

I.3. Government Offices

City of Toronto

City of Edmonton

City of Montreal

City of Regina

City of Vancouver

City of Winnipeg

City of Saint John

I.4 Building Owners

Mr. R. Kavanagh
Engineering Services
Cadillac Fairview Residential Management
1200 Sheppard Avenue E.
Willowdale, Ontario
M2K 2R8
(416) 497-1800

Rayview Summit Limited
1085 Steele Avenue West
Toronto, Ontario

Federal Accelerated Capital Cost Allowance:

Class 34

FEDERAL TAX INCENTIVE — for energy recovery and alternative energy sources.

This incentive is an accelerated capital cost allowance designed to encourage business and industry to reduce energy waste, to decrease its dependence on oil, and to switch to renewable energy resources.

Simply stated, it is a "fast write-off" which applies to machinery and equipment which form part of a system as listed in Class 34 of the Income Tax Regulations. In these Regulations eligible assets that save energy or use renewable sources of energy can be written off over:

2 years if acquired within the eligible period but before November 12, 1981 (up to 50% in the first year and the balance in any subsequent year).

3 years if acquired within the eligible period but after November 12, 1981 (up to 25% in the first year, up to 50% in the second year and the balance in any subsequent year).

Without this accelerated write-off, the rates applied to these types of assets would be either 6% or 20% calculated on a declining balance basis.

REMINDER

If your equipment qualifies for Capital Cost Allowance under Class 29 you would enjoy similar benefits without having to make application under Class 34. Refer to Revenue Canada's Interpretation Bulletin IT-147R.

KINDS OF EQUIPMENT AND SYSTEMS THAT QUALIFY

The new types of assets which have been added to Class 34 include equipment used to generate electricity at small hydro-electric sites, heat recovery equipment, and equipment employed in a wide range of active solar heating systems.

Included in the current Regulations are systems which were previously eligible for the accelerated tax write-off in the 1976 Income Tax Regulations. In the revised Regulations, however, the period of eligibility has been extended to 1985.

Also eligible are assets which:

a) produce and/or distribute heat,

b) produce electricity,

c) simultaneously produce heat and electricity.

ELIGIBILITY PROVISIONS

To qualify for the fast write-off, an asset must be acquired before 1985 and have been purchased by a Canadian taxpayer for use in a business in Canada and must also be certified by the Minister of Energy, Mines and Resources.

Obtain your application form for certification (or for a "prior opinion") by writing to:

Tax Incentive Programs Secretariat -
Conservation and Renewable Energy Branch
Department of Energy, Mines and Resources
580 Booth Street
Ottawa, Ontario
K1A 0E4
Telephone (613) 995-9447

If possible, include with your application a simple block diagram or schematic of the equipment or system, a list of installed capital costs, and a brief explanation of the system. These will speed up the processing of your application.

COVERAGE DETAILS

Below is an *abbreviated* list of the types of assets that now qualify for a three-year write-off. For full coverage details, consult Class 34 of the Income Tax Regulations or contact the Tax Incentive Programs Secretariat.

ASSETS WHICH QUALIFY:

A. *Heat Recovery Equipment and/or System* that is designed to conserve energy or to reduce the requirement to acquire energy by *extracting* and *reusing* heat from thermal waste, for example, heat exchangers, condensers, and associated pumps, fans, instruments and control panels.

B. *Small-scale Hydro-electric Generating Equipment* (including alterations which increase capacity) up to a total of 15 megawatts.

C. *Active Solar Heating Equipment and Systems* which furnish heat for *manufacturing* and *processing*, and/or space heating in a new building, and heating of water.

D. *Equipment and/or System Used to Generate Heat by Combustion of a Fuel Other Than Oil* (natural gas, coal, coal gas, lignite, peat, wood wastes or municipal wastes or any combination thereof).

If Acquired *After May 25, 1976* and Before 1985:

E. *Equipment and/or System Used to Generate Heat* by combustion of municipal wastes and/or wood wastes.

F. *Equipment and/or System Which Produces Heat and Electricity* provided the consumption of fossil fuel chargeable to the electricity generated is less than 7,000 Btu per kWh of electrical energy produced.

G. *Equipment and/or System Employed to Recover Industrial Byproduct Heat.*

Also eligible under categories D, E, F and G are the assets used to distribute heat and to generate electricity.

Buildings and structures are not included except under item B above.

ASSETS AND PROCESSES NOT COVERED BY THE PROGRAM

- Used equipment unless it had been previously included in Class 34 for income tax purposes.
- Equipment, instruments and/or controls for improving the efficient use of energy, e.g., boiler fine tuning and instrument monitoring control.
- Insulation of buildings or equipment.

A piece of equipment does not qualify unless it is part of an eligible system.

The department will not endorse a manufacturer's product.

One more way the Government of Canada is helping Canadians conserve energy